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THE VALUE OF VISIBILITY AND RFID IN TRANSSHIPMENT OPERATIONS – A SIMULATION STUDY

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Abstract
Shrinkage can lead to inventory record inaccuracy which in turn may negatively affect the performance of supply chain control policies. In this paper the impact of shrinkage on the efficiency of transshipment operations is demonstrated using stochastic simulation. In particular, the value of full inventory visibility which could be achieved using RFID is approximated. This value is shown to be relatively low given the assumed properties of the transshipment policy. Our preliminary results suggest waiting for further tangible benefits of RFID before building its business case in transshipment environments.

1. Introduction

In today's competitive economic environment supply chain management practices have become critical factors for success. Leading companies from different industries such as Dell, Wal-Mart or Zara are successful in the marketplace not only because they offer the right products but also because their processes are aligned to delivering these products in an efficient way. Dell has optimized the trade-off between product configurability and speed of delivery [4]. Wal-Mart is able to offer very low prices due to highly efficient logistics operations [14]. Zara successfully applies a quick response formula consisting of lead time reduction and efficient information sharing mechanisms [5]. When taking a closer look at these cases it turns out that information technology plays a vital role in the successful implementation of supply chain strategies. Dell has closely linked the control of the supply chain practices that enable product configurability with their website [4]. The website can also be used to efficiently steer demand to close the gap between short-term supply and demand. Wal-Mart has heavily invested into the latest information technology in order to automate processes and collect relevant sales data [14]. Zara takes advantage of technology that facilitates the flow of information reflecting consumer trends (e.g. handheld devices at stores) or technologies which help to reduce the lead time (computer aided design, fully automated distribution centers) [5].

Radio Frequency Identification (RFID) is an information technology, whose impact on supply chain management has been rising steadily. It allows for the contactless and concurrent identification of several 'tagged' objects at a time and can therefore significantly increase the

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efficiency and accuracy of data collection in supply chain processes. Wal-Mart has mandated their major suppliers to attach RFID transponders to pallets in order to make their automated distribution centers even more efficient. Others are still hesitating to introduce the technology, mainly because of the still high transponder prices and uncertain financial benefits.

The most fundamental tradeoff in supply chain management exists between efficiency and agility. Efficiency in the supply chain context refers to the minimization of production and distribution cost. Agility refers to the degree to that a supply chain is able to efficiently cope with supply and demand uncertainty. The tradeoff comes into existence because agility has to be paid for, e.g. in the form of higher safety inventory, higher setup costs, and acceleration of transportation. The introduction of innovative information technology in the supply chain can have consequences both with respect to efficiency and agility. For instance, if it enables the reduction of labor cost in distribution centers it has an impact on efficiency; if IT enables the implementation of supply chain practices that reduce the exposure to supply and demand risks it has an impact on agility.

In this paper the impact of RFID on the efficiency of transshipment operations is assessed. The term transshipment refers to the operational supply chain practice of transporting inventory between locations that should be able to satisfy demand immediately from stock. Transshipments can significantly increase the agility of a distribution system.

The focus of this paper is on the benefit of full inventory visibility that is made possible by RFID. Effective transshipment operations require a sophisticated information system that is capable of determining transshipment quantities based on inventory levels and demand rates at different sites. Inventory inaccuracy caused by shrinkage and other unwanted real-world influences on the flow of goods may therefore decrease the efficiency of transshipments; the question remains by how much full visibility can reduce distribution costs and under which circumstances. The paper at hand provides answers to these questions based on the results of a simulation study. Our results suggest that other tangible benefits of RFID should be awaited until its business case in distribution systems with transshipments is built.

2. Related Work

A recent survey by Chiou provides a good overview of the current state of research on transshipments [3]. Numerous authors have evaluated the use of transshipment in service part systems [10]. Since the demand for service parts (e.g. airplane components) is usually low and highly uncertain and because the storage of such parts is usually expensive, efficient use of inventory can usually be improved by implementing a transshipment policy. Recently, transshipments have also been considered in retail settings. According to Chiou [3] transshipment policies can be classified into emergency transshipments and preventive policies as well as mixed policies. Emergency transshipments are considered only if demand is backlogged, whereas preventive transshipments are supposed to balance the inventory at several consumption sites in order to prevent the out-of-stock situations. Preventive policies can also be applied to scenarios where demand is not backlogged but lost if it cannot be immediately satisfied.

The determination of optimal transshipment quantities based on the inventory levels at different consumption sites has turned out to be highly complex. Numerical optimization models under specific assumptions have for example been proposed by Herer et al. [7] and Lee [10]. The optimization procedures used in these models take the trade-off between inventory holding, stock-out and transportation costs into account. Other authors have specified and evaluated the performance of less sophisticated transshipment mechanisms that do not implicitly optimize complex cost tradeoffs [11][2]. These transshipment policies have the advantage that they are based on fewer assumptions and can thus be applied to more general supply chain settings.

Transshipments can only be implemented if the information required to determine transshipment quantities is accessible and sufficiently accurate. A number of authors have stressed the potential of RFID in increasing the accuracy and accessibility of inventory information and thereby indirectly improving the efficiency of supply chain management practices [12]. Inventory inaccuracy can have different reasons in practice, e.g. theft, misplacements, transaction errors, unreliable delivery processes, and quality problems [13]. The effect of inventory inaccuracy on the performance of particular supply chain practices was analyzed by several authors. Atali et al. quantified its impact on the performance of a regular order policy [1]. Fleisch and Tellkamp simulated a typical retail supply chain and analyzed the impact of inventory record inaccuracy on performance [6].

To the best of our knowledge the impact of inventory record inaccuracy on transshipment operations – and therefore also the potential information value of RFID in transshipment operations – has not been subject to quantitative research. We close this research gap by conducting a simulation study of a distribution system with transshipments that is subject to shrinkage.

3. Model

3.1 Basic Assumptions and Order Policy

We simulate a distribution system consisting of one central warehouse and *N* sites that have to satisfy demand immediately from stock. Daily demand at each consumption site follows a normal distribution with mean μ_d and standard deviation σ_d. The different sites receive shipments from the central warehouse in regular time intervals of length R days. It takes *L* days to ship ordered items from the central warehouse to the consumption sites. If the demand at a site cannot be immediately satisfied from stock, a penalty cost of c_p is incurred per unit and day. The stock on hand at consumption site *i* at time *t* is abbreviated by o_i^t; the size of backlog at time *t* at site *i* is denoted by b_i^t.

The existence of a central decision maker is assumed. This decision maker reviews the inventory levels at all locations every R^{th} day and initiates a regular shipment of approximately optimal size. The applied periodic review order policy is approximated by the optimal continuous review policy. The algorithm used to compute the required parameter values take as inputs the yearly holding cost per unit (c_h), the backlogging cost per unit and day c_p, the mean demand during the lead time (lead time demand), the standard deviation of lead time demand, and the ordering cost c_o incurred per order. Mean and standard deviation of lead time demand can be computed by folding the distribution of period demand (R+L) times. Ordering cost is set to zero since orders are placed periodically and order sizes are always greater than zero.

3.2 Transshipment Policy

Additional to the regular shipments, stock can be transshipped between sites at the end of each day at a cost of c_t per unit. The quantity tq_{ij}^t that is transported from site *i* to site *j* at time *t* is determined by the central decision maker based on the current inventory and backorder levels at each site *i* and the knowledge about the parameters of the demand distribution.

The applied transshipment policy was proposed by Lee et al. [11] and belongs to the family of mixed transshipment policies: items can be transported from location *i* to location *j* in order to satisfiy backlogged demand or to prevent future stock-out situations. The algorithm used to determine the final transshipment quantities tq_{ij}^t can be subdivided into *three phases* which are described in the following.

In the *first phase*, sites that have excess stock and sites that require stock are determined. The corresponding criterion is based on the type 1 service levels *a*, *b*, and *c*. The corresponding parameters are p_a, p_b, and p_c; they specify the probability with which the service level assures that no stock-outs occur during a particular period of time. A site is considered in need of stock if condition (1) is met.

$$INT[(t \bmod R)\mu_d + p_a\sqrt{(t \bmod R)}\sigma_d + 0.5] < o_i^t - b_i^t \tag{1}$$

A site is considered to have excess stock if its current inventory and backorder levels meet condition (2).

$$INT[(t \bmod R)\mu_d + p_c\sqrt{(t \bmod R)}\sigma_d + 0.5] \geq o_i^t - b_i^t \tag{2}$$

The central decision maker strives to satisfy service level *b* (the target service level) using transshipments. In order to bring the inventory level of a site *j* in need of stock up to the level prescribed by service level *b*, the quantity rq_j^t is required. It is calculated in the following way:

$$rq_i^t = \begin{cases} \max\left\{INT\left[(t \bmod R)\mu_d + p_b\sqrt{(t \bmod R)}\sigma_d + 0.5\right],0\right\} - o_i^t + b_i^t \;\; if\ (1)\ is\ true \\ 0\ otherwise \end{cases} \tag{3}$$

According to its transshipment service level *a*, a site *i* that has excess stock at the end of period *t* can afford to offer aq_i^t items. This quantity is calculated according to expression 4.

$$aq_i^t = \begin{cases} o_i^t - \max\left\{INT\left[(t \bmod R)\mu_d + p_a\sqrt{(t \bmod R)}\sigma_d + 0.5\right],0\right\} \;\; if\ (2)\ is\ true \\ 0\ otherwise \end{cases} \tag{4}$$

The parameters of the transshipment service levels follow condition 5.

$$0 < p_c \leq p_b \leq p_a < 1 \tag{5}$$

The portion of rq_i^t that exceeds the current backlog (i.e. the expected future stock-out) is denoted by rqe_i^t and can be calculated by subtracting b_i^t from rq_i^t. The values of rq_j^t and aq_i^t cannot be directly used in the transshipment policy because the supply $AQ^t = \sum_{i=1}^{N} aq_i^t$ and demand $RQ^t = \sum_{i=1}^{N} rq_i^t$ for items in the entire system usually differs. Thus, if the demand for parts is higher than supply, the available stock available for transshipment has to be rationed. Therefore in the *second phase* of the algorithm, the required quantities rq_i^t are adjusted to $\overline{rq}_i^t$ in the following way ($B^t = \sum_{i=1}^{N} b_i^t$ and $RQE = \sum_{i=1}^{N} rqe_i^t$):

$$If\ B^t < AQ^t < RQ^t\ then\ \overline{rq}_i^t = b_i^t + \frac{rqe_i^t (AQ^t - B^t)}{RQE^t} \tag{6}$$

$$If\ AQ^t \le B^t\ then\ \overline{rq}_i^t = \frac{b_i^t AQ^t}{B^t} \tag{7}$$

The final transshipment quantities are determined in the *third phase* of the algorithm following an iterative matching approach. The outcome of every matching step is the amount of parts which is going to be shipped from site *i* with the highest value of aq_i^t to site *j* with the highest $\overline{rq}_j^t$. After each iteration, the determined quantity tq_{ij}^t gets subtracted from aq_i^t and $\overline{rq}_j^t$. The matching procedure is continued until $\sum_{i=1}^{N} \overline{rq}_i^t$. The actual transshipments are executed immediately after each iteration of the matching procedure.

3.3 Consideration of Inventory Inaccuracy

Inventory inaccuracy is defined as the discrepancy between physical and virtual inventory levels [1]. Three common reasons for inventory inaccuracy are mentioned in the literature: shrinkage, misplacements and transaction errors. Shrinkage refers to unwanted loss of inventory, e.g. due to theft or spoilage: it leaves the virtual inventory level unchanged but reduces the physical one. Misplacements occur when items are removed from the place where they can be readily used to satisfy demand. They reduce the physical inventory until they are moved back to their usual place. Transaction errors occur when the inventory record is not correctly updated after a transaction. They only affect virtual inventory levels.

Transshipment quantities are determined based on system inventory (i.e. the virtual stock levels); the difference between virtual and physical stock levels that can result from all of the mentioned error sources could adversely influence the efficiency transshipment policy and eventually lead to decreased performance. In this paper we only consider one common reason for inventory inaccuracy, namely shrinkage.

We introduce shrinkage into the model by adding an additional source of demand at each site. The shrinkage at each site *i* in period *t* reduces the physical on-hand inventory level at each site but does not affect the backorder level. The amount of shrinkage occurring during each period is modeled using a lognormal distribution with mean μ_s and standard deviation σ_s. According to [8] the lognormal distribution can be used as a preliminary model in the absence of real-world observations. In contrast to the Poisson distribution which was used to model shrinkage before [1], the lognormal function allows for the explicit specification of variance. Furthermore, it can only take on positive values and is suitable for modeling low means. The mean number of inventory lost in each period is linked to the mean demand by the factor α, i.e. $\mu_s = \alpha\mu_d$. Before the inventory is reviewed in order to determine the size of the regular order, the virtual stock levels are set to the physical stock level. Therefore, the order policy is not influenced by inventory inaccuracy and the impact on performance can be entirely attributed to its effect on transshipments. In case a transshipment from *i* to *j* which was determined based on inaccurate virtual inventory levels cannot be fully executed because the physical stock at site i does not suffice ($o_i^t < tq_{ij}^t$), as many parts as possible are transshipped (o_i^t items). Since the actual transshipments are executed right after the determination of transshipment sizes and the matching procedure described in section 3.2 proceeds in decreasing order to the stock required and offered, the prevention of the largest stock-outs is prioritized.

4. Simulation Study

4.1 Experimental Setup

A simulation model was implemented in the programming language Java using the SSJ library for stochastic simulation [9]. Table 1 provides an overview of the input parameters required for the definition of one instance of the supply chain simulation model. The factorial design of the simulation study implies the simulation of 7040 different instances of the model. In order to assure statistical validity, each simulation was carried out 2,000 times. The simulated time horizon is 1080 periods. This corresponds to approximately 3 years. Based on Welch's procedure, a safe warm-up period of 900 periods based on the moving average of on-hand inventory was determined [8].

Table 1. Simulation parameters (* indicates default values)

Parameter	Value Range	Description
c_h	{5*, 10}	Yearly holding cost per item
c_b	{50*, 100}	Backordering cost per item and period
c_t	{1*, 5}	Transshipment cost per item
μ_d	20	Mean demand during one period
cv_d	1	Coefficient of variation of demand during one period
α	{0%, 1%, …, 10%}	Rate of unobserved inventory loss
cv_s	{1, 2, 3, 4, 5}	Coefficient of variation of unobserved inventory loss
R	30	Review period
L	10	Regular lead time
(p_a, p_b, p_c)	(0.9, 0.8, 0.7)	Parameters of transshipment service levels
I_{TS}	{0, 1}	Use of transshipments
I_{RFID}	{0, 1}	Use of RFID
I_{SA1}	{0, 1*}	Use of adjusted order policy
I_{SA2}	{0, 1*}	Use of adjusted transshipment policy

The parameters were chosen in a way such that transshipments are economically advantageous:

- Backlogging cost is high compared to transshipment cost.
- Backlogging cost is high compared to inventory holding cost.
- The regular replenishment lead time is significantly longer than the transshipment lead time.

Apart from I_{TS}, I_{RFID}, I_{SA1}, and I_{SA2} all input parameters have been described in section 3. If I_{TS} is equal to 1, the transshipments between consumption sites are allowed and the transshipment policy is applied; otherwise the regular replenishments are carried out.
If I_{RFID} is equal to 0, the transshipment policy is based on potentially inaccurate virtual inventory levels, otherwise it is executed based on physical inventory levels. This allows for measuring the impact of inaccurate inventory data on the performance of the distribution system.
If the central planner is aware of the mean inventory loss between subsequent replenishments, she might want to adjust the optimal order quantity by exactly this amount in order to dampen negative effects on system performance [1]. If parameter I_{SA1} is equal to 1, the order quantity is increased by $(R+L)\mu_s$.
According to Lee and Özer [12], the impact of RFID should be isolated by all available means in order to determine the 'true value of visibility'. In other words, the benchmark system with which the RFID-enabled system is compared should take advantage of all available information except the information which can only be obtained using RFID. The parameter I_{SA2} allows for considering the average shrinkage level in transshipment operations: if it is set to 1, μ_d in equations (1) to (4) is replaced by $(\mu_d + \mu_s)$. Moreover, the virtual stock levels are adjusted by μ_s after each period.

The output of each simulation run consists of four values: the average total cost per period (ToC), the average inventory holding costs per period (HoC), the average backlogging costs per period (BaC), and the average transshipment costs per period (TrC).

4.2 Results

In order to quantify the information value of RFID in the distribution setup described above, the performance of three distribution systems was compared: The *basic system* which does not allow for transshipments (I_{TS}=0), the *benchmark system* which uses transshipments based on inaccurate inventory levels (I_{TS}=1, I_{RFID}=0), and the *RFID-enabled system* in which transshipment operations are based on physical inventory (I_{TS}=1, I_{RFID}=1).

For the initial comparison of the different distribution systems the parameters c_h, c_b, c_t, cv_d, I_{SA1} and I_{SA2} were set to their default values while the parameters α and cv_s, which determine the level of inventory inaccuracy caused by shrinkage, were varied. In order to make sure that the observed differences between the total cost values are statistically significant, their 95% confidence intervals were calculated.

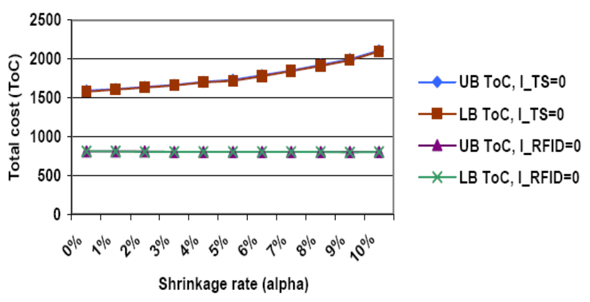

Figure 1: ToC confidence intervals for basic and benchmark system ($cv_s = 5$)

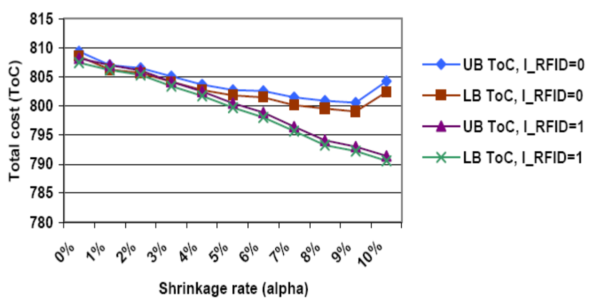

Figure 2: ToC confidence intervals for benchmark and RFID-enabled system ($cv_s = 5$)

Figure 1 shows the total cost confidence intervals for the basic and benchmark system for different values of α. The performance drop of the basic system in response to growing levels of shrinkage is not surprising: although the order quantities cover the mean amount of shrinkage until the next replenishment (I_{SA1}=1), the variability of inventory loss and the corresponding trade-off between holding and backlog costs is not considered by the order policy. Therefore it can be expected to be suboptimal in the presence of stochastic inventory loss. The analysis of the different cost components (HoC, BaC, and TrC) revealed that most of the performance advantage of the benchmark over the basic distribution system stems from the reduction of backlogging cost. While transshipments eliminate stock-outs (by 100% at α=0, by 99% at α=0.1), holding costs are reduced only marginally (by 0.9% at α=0 and 1.6% at α=0.1). Transshipment costs in the benchmark system increase linearly with the level of shrinkage (from 6 to 9).
Figure 2 shows the confidence intervals for total cost of the benchmark and the RFID-enabled distribution system. A slight performance advantage of the RFID-enabled system is visible. However, it only becomes statistically significant from a shrinkage level of 5% onwards. Furthermore, for levels of cv_s below 3 the performance advantage of the RFID-enabled system was not significant, i.e. the confidence intervals overlap.

The analysis of cost components indicates that the slight increase of performance achieved by full visibility results from a better ability to prevent the negative financial impact of backlog. While the percentage of prevented backlogging costs slowly declines with increasing shrinkage levels in the benchmark system, the RFID-enabled system maintains a prevention rate of 100%. The slight drop of the mean total cost of the RFID-enabled system can be explained by the effect which shrinkage has on holding cost: since shrinkage reduces the average number of items kept in stock, holding costs decline with growing values of α. We found no statistically significant difference between the benchmark and the RFID-enabled system with respect to holding and transshipment costs.

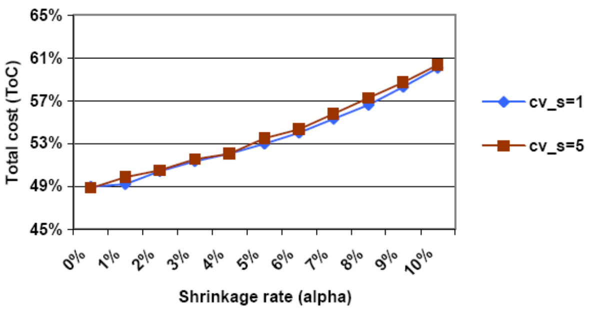

Figure 3: Relative ToC improvement of from basic to benchmark system

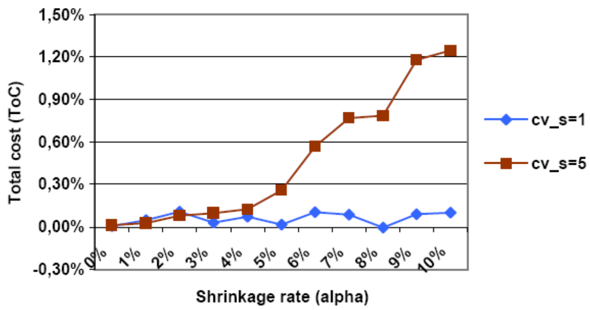

Figure 4: Relative ToC improvement from benchmark to RFID-enabled system

Figure 3 shows the relative advantage in terms of total costs achieved by the benchmark system compared to the basic system for the lowest (cv_s=1) and highest level (cv_s=5) of shrinkage variability. This advantage is very high (about 50%) for the chosen cost parameters. For the reasons given above, the advantage increases with higher levels of shrinkage. The result is robust with respect to different levels of shrinkage variability.

Figure 4 demonstrates the relative advantage of the RFID-enabled distribution system over the benchmark system. Even at high levels of shrinkage it stays below 1%. Moreover, the benefit of full visibility crucially depends on the level of variability of the shrinkage process. If the corresponding coefficient of variation stays low, visibility does not seem to posses any value at all – even at high shrinkage rates.

4.3 Sensitivity Analysis

The applied transshipment policy does not optimize the trade-off between holding, backlogging and transshipping cost. Therefore the impact of the exogenous variables c_h, c_b, and c_t on the relative improvements achieved by transshipments and RFID was evaluated in a sensitivity analysis.

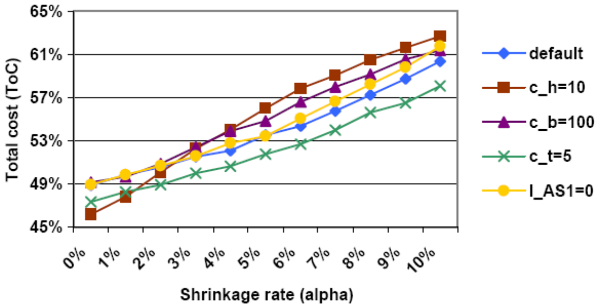

Figure 5: Relative ToC improvement of from basic to benchmark system

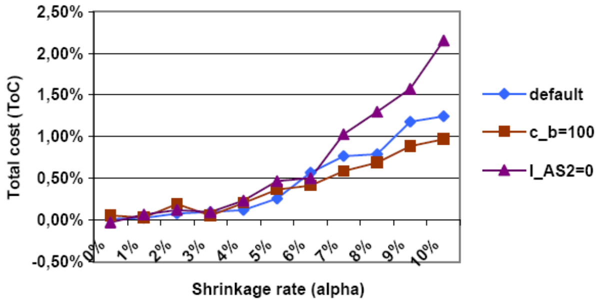

Figure 6: Relative ToC improvement from benchmark to RFID-enabled system

Figures 5 shows the effect of unilateral increases of each of the three cost parameters and the inventory cover parameter I_{AS1} for cv_s=5. An increase of unit transshipment cost by factor 5 reduces the advantage of the benchmark system over the basic system by about 2% independent of the level of shrinkage. This result indicates that shrinkage does not reduce the number of transshipments conducted on average. It also shows that shrinkage does usually not cause situations in which a site with excess stock is not able to deliver the promised transshipment quantity. The change of transshipment benefit in response to a change of I_{AS2} was not significant.

As expected, an increase of unit holding or backlogging cost leads to an increase of the relative advantage of the benchmark system, however only from a certain shrinkage level (3%) onwards.
As figure 6 shows, the relative advantage of the RFID-enabled distribution system over the benchmark system is smaller if unit backlogging cost is higher and greater if the average shrinkage level is not considered in the determination of transshipment quantities. The first result is unintuitive at first sight since backlogging cost is the only cost component which is significantly reduced by full visibility. The explanation is that a higher unit backorder cost causes the regular order quantity to increase which in turn reduces the probability of stock-out. The second result underlines the insight of Lee et al. that an 'informed' policy performs better than a 'naïve' one [12]. The change of RFID benefit in response to a change of c_h, c_t and I_{AS1} was not significant.

4.4 Discussion

While our results confirm the potential of transshipments in distribution systems, they do not indicate a particularly high value of full inventory visibility in distribution systems subject to shrinkage. Even for very high and variable shrinkage rates the potential improvement rarely exceeds 1%. For realistic shrinkage rates, e.g. 1-2% in retailing [6], the information value of RFID can thus be neglected in the specified setting. A possible explanation for this result is the apparent robustness of the chosen transshipment policy to the kind of inventory record inaccuracy caused by shrinkage. As described in section 3, the transshipment quantities are determined based on system-wide supply and demand information. Unobserved shrinkage only affects inventory levels since it cannot cause backlog. Thus, since supply information is overstated and backlog information remains correct, the effectiveness of transshipments with respect to existing backlog stays intact in spite of increasing levels of unobserved inventory loss.

5. Conclusions

The elimination of inventory inaccuracy is a possible benefit expected from the introduction of RFID in supply chains. In this paper, the effect of shrinkage and the resulting visibility decrease in a distribution system with transshipments is demonstrated using stochastic simulation. Although the results obtained from the simulation are highly dependent on the model assumptions and input parameters, they allow for an initial assessment of the size of RFID's information value in agile distribution systems subject to shrinkage.

Although our analysis has shown that the benefit of RFID in the defined setting is rather limited, further research using different transshipment policies and input parameters is definitely warranted in order to prevent understating the value of full inventory visibility made possible by RFID. In particular, the impact of full inventory visibility on preventive transshipments could be isolated. In such environments visibility may be more valuable since transshipment policies would be based exclusively on inventory levels.

Finally, transshipments represent a supply chain practice that is highly demanding in terms of data accuracy and execution effort simply because control takes place on a highly disaggregated level. Therefore RFID could bring about other efficiency gains related to transshipment operations, e.g. the reduction of handling costs.

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